Towards Quantization Index Modulation Strategies on Content-based Watermarking Schemes

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Abstract

A content-based watermarking strategy relying on an affine invariant embedding domain obtained from affine invariant interest points and a watermark insertion via quantization index modulation is analyzed, namely the effects on the performance of the whole watermarking scheme carried out by the presence or absence of interpolation operations during the design of the invariant domain.

1. Introduction

Digital watermarking has been pointed out as one promising and suitable technology for applications such as copyright protection, fingerprinting or authentication of multimedia content. Despite the recognized virtues exhibited by such technology, some practical problems still unsolved, namely the robustness of watermarks. For instance, resilience to geometric transformations is still regarded as an open issue in digital image and video watermarking. It is one of the reasons why digital watermarking as a mean of solving problems related to the diffusion of multimedia content [1] has not achieved the effectiveness that was initially predicted. Nevertheless, several solutions attempting to provide robustness to geometrical transformations have been proposed. These solutions can be broadly divided into four categories: invariant-based methods, template-based methods, self-synchronization-based methods and content-based methods. The first category includes methods exploiting invariant or partially invariant domains for watermark insertion, *e.g.*, using the Fourier-Mellin transform [14, 20] or the Radon transform [16]. The main limitation of invariant-based methods is the need of interpolation in order to obtain the invariant domain. Mostly due to the inaccuracy of interpolation methods, the performance of these solutions tends to be affected. Methods from the second category provide robustness to geometric distortions by retrieving artificially embedded references (templates) which are used as a mean of identification of geometric transformations and are able to revert them [15]. Those methods affect the image fidelity due to the addition of the reference signal. Furthermore, templates can be straightforwardly removed [7]. Self-synchronization-based methods are analogous to template-based methods in the sense that they achieve robustness by identifying geometric distortions, however, the watermark itself can be used to identify the transformation [5, 4]. Such approaches are fragile to filtering, namely low-pass filtering. Content-based schemes, often referred to as second generation methods [8], are aware of perceptually significant portions of data which can be used as a reference in terms of location and direction of the watermark. Among the several perceptually significant portions of data, feature points have been widely used on the design of content-based schemes essentially as a consequence of some intrinsic properties of these descriptors: (i) they can be seen as locations where the image is more significant, thus, the adoption of a local watermark embedding strategy will be able to provide resilience to cropping (if the information is hidden in the neighborhood of such features, taking into account that the cropped version of the marked image contains the most significant content of the original image); (ii) detection of such features can provide invariance to some content transformations such as background clutter, occlusion or image rotation. For example, Kutter *et al.*[8] and Hang and Tang [17] exploited strategies based on feature points retrieved by the Mexican Hat wavelet scale interaction method. In the first scheme, a Voronoi diagram was computed from the detected features to define the embedding regions; in the latter one, the features were used as references to embed the watermark into a normalized representation of the points neighborhood. Bas *et al.* [2] introduced a solution relying on feature points given by the Harris-Stephens operator [6]. From these features, a Delau-

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nay tessellation was created that later was applied to embed the watermark. An improved version of the Harris-Stephens operator was also applied by Weinheimer *et al.* in [19]. In their scheme, the watermark embedding strategy is similar to the one presented in [17].

The fact that the effectiveness of a content-based watermarking scheme depends on the effectiveness of the feature detector has revealed to be one of the main disadvantages of feature-based watermarking solutions, since feature detectors usually do not exhibit the desired stability/repeatability in the presence of image distortions. Moreover, content-based methods have shown to be computationally complex. A content-based scheme was introduced in [11], providing robustness with respect to geometric distortions, namely the affine ones. This kind of robustness was partially achieved by embedding the watermark into the (α,β) domain, an affine invariant space, which was obtained, firstly, by detecting features known as affine invariant interest points [12, 10] and defining triangle-shaped regions identified by the interest points. Unlike most of the invariant embedding spaces proposed in literature which are obtained from the image spectral domain, the proposed space is obtained directly from the spatial domain. By doing this, the affine invariant domain can be easily used as the starting point of any other invariant domain. Furthermore, the invariant space does not constrain the embedding strategy. Herein, we focus on the performance of a watermarking strategy *via* Quantization Index Modulation (QIM)[3, 13, 9] which adopts the (α,β) domain as the embedding space. As highlighted in [11], the embedding and extraction processes can be performed without carrying out a mapping relying on interpolation. In this paper, we analyze the importance of avoiding an interpolation operation in terms of the effectiveness of the watermarking scheme by presenting two versions of a QIM watermarking strategy whose main difference is the presence of an interpolation stage in one of the schemes in order to obtain the invariant space.

The remainder of this paper is organized as follows: Section 2 describes two versions of a quantization-based watermarking strategy which uses the (α,β) domain as the embedding space; in Section 3, experimental results regarding the robustness of the schemes with respect to geometric transformations and common distortions are presented; finally, in Section 4, conclusions are addressed.

2. Watermarking in the Alpha-Beta Domain

The (α,β) domain is a coordinates system derived from the barycentric coordinates and it can be seen as a normalized representation of triangles in the presence of affine transforms. Figure 1 illustrates the operations required to obtain the affine invariant space. Given an image, triangular sub-images are obtained using affine invariant interest points [12] as vertices. Before detecting points, the image is adaptively LUM-filtered [10] in order to improve the repeatability of the detector in the presence of geometric distortions. Figure 2 shows the results on the interest point detection after applying the adaptive filter. For each point inside the triangle, the barycentric coordinates with respect to the vertices (three non-collinear interest points) are computed.

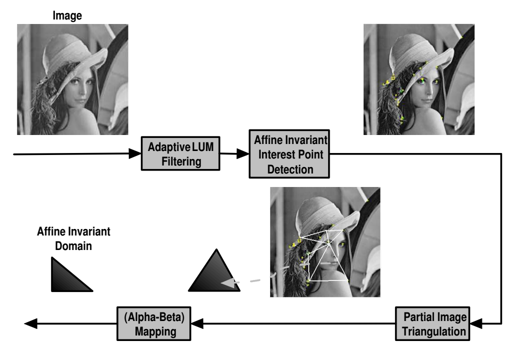


Figure 1. Diagram of the operations performed to obtain the affine invariant space.

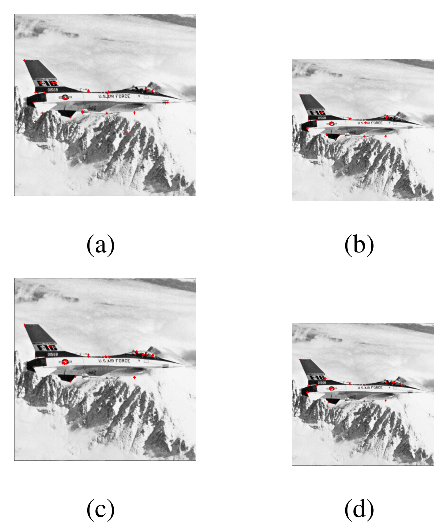


Figure 2. "F16" image and its affine invariant interest points: (a) original(512×512 pixels); (b) resized to 410×410 pixels; (c) original(512×512 pixels, pre-filtered); (d) resized to 410×410 pixels (pre-filtered).

In the design of the invariant domain, the following properties have been exploited:

Property 1 *Let* $\mathbf{x_1}$, $\mathbf{x_2}$ *and* $\mathbf{x_3}$ *be the vertices of a triangle* T*. Each point* $\mathbf{x} \in T$ *can be expressed as a convex combination of* $\mathbf{x_1}$, $\mathbf{x_2}$ *and* $\mathbf{x_3}$*:*

$$\mathbf{x} = \alpha\mathbf{x_1} + \beta\mathbf{x_2} + \gamma\mathbf{x_3}, \tag{1}$$

where $\alpha, \beta, \gamma \geq 0$ *and* $\alpha + \beta + \gamma = 1$.

The α, β and γ values are the barycentric coordinates of $\mathbf{x}$ with respect to T, and for any interior point $\mathbf{x}$, they can be expressed as ratios of triangle areas: each coordinate can be seen as weight of a vertex and its value is the ratio between the area of the triangle identified by $\mathbf{x}$ and the other two vertices which are not weighed by the coordinate and the whole triangle area. Since $\alpha + \beta + \gamma = 1$, the convex combination in Equation (1) can be rewritten as

$$\mathbf{x} = \alpha(\mathbf{x_1} - \mathbf{x_3}) + \beta(\mathbf{x_2} - \mathbf{x_3}) + \mathbf{x_3}. \tag{2}$$

Property 2 *The coordinates* (α,β) *are invariant to affine transformations over* $\mathbf{x}$*.*

Property 3 *In the* (α,β) *domain, a triangle in Cartesian coordinates is converted into a right-angled triangle identified by the vertices* $(0,0)$*,* $(1,0)$ *and* $(0,1)$*.*

Therefore, obtaining the (α,β) domain can be seen as a process of normalizing triangular regions in the presence of affine transforms, as illustrated in Figure 3. As it was

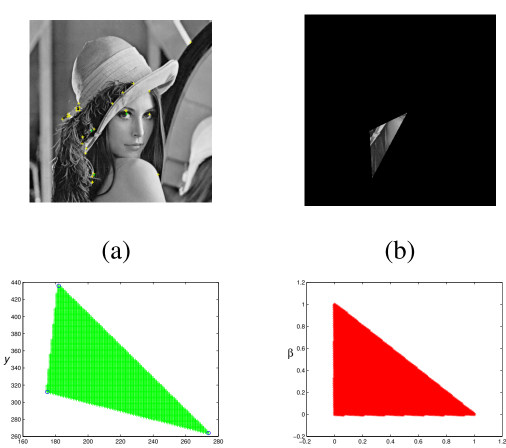


Figure 3. Obtaining the (α,β) space: (a) "Lena" image and its affine invariant points; (b) triangle obtained from the three strongest points; (c) triangle representation in Cartesian coordinates; (d) triangle representation in (α,β) coordinates.

aforementioned, the proposed space can be used as a stable framework for different watermarking solutions. In this section, we present a watermarking solution combining the advantages of having an affine invariant embedding domain and an informed embedding technique by means of QIM. The main reasons for this choice were: (i) QIM embedding systems outperform spread spectrum blind watermarking systems, when it comes to the watermark capacity, which is an extremely important feature, since the watermark is locally embedded, usually in small regions; (ii) these schemes usually do not exhibit resilience to geometric transformations, thus the addition of invariance will improve their effectiveness.

Selecting suitable regions to be marked is a crucial stage in the embedding process. The choice is performed by evaluating, for each triangle, the following features: (i) the relative area; (ii) the distance to the image centroid; (iii) the texture level; (iv) the strength of the vertices.

Suppose we have p non-overlapped triangles, the relative area of a triangle T_j is given by Eq. (3), where A_j denotes the number of pixels in T_j.

$$\bar{A}_j = \frac{A_j}{\max_{i\in\{1,\ldots,p\}}\{A_i\}}, \tag{3}$$

The image centroid of an image $m \times n$ I is

$$\mathbf{c} = (\sum_{x=1}^{m}\sum_{y=1}^{n} xh(x,y), \sum_{x=1}^{m}\sum_{y=1}^{n} yh(x,y)), \tag{4}$$

where $h(x,y) = \frac{I(x,y)}{\sum_{u=1}^{m}\sum_{v=1}^{n} I(u,v)}$. The distance between T_j and $\mathbf{c}$ is defined via the equation

$$\mathrm{dist}(T_j,\mathbf{c}) = \frac{\left\|\mathbf{c} - \mathbf{c}_{T_j}\right\|}{\max_{i\in\{1,\ldots,p\}}\{\left\|\mathbf{c} - \mathbf{c}_{T_i}\right\|\}}, \tag{5}$$

where $\|\cdot\|$ is the Euclidean norm and $\mathbf{c}_{T_j}$ is the centroid of the triangular image T_j.

Texture level is defined according to Equation (6), where NVF denotes the *Noise Visibility Function* [18].

$$Text_j = mean(1 - NVF(T_j)) \tag{6}$$

Texture is evaluated in order to improve the watermark imperceptibility. The strength of T_j is given by

$$str_j = \sum_{i=1}^{3} \frac{6}{\mathrm{r}(v_{j_i})}, \tag{7}$$

where $\mathrm{r}(v_{j_i})$ denotes the rank of vertex i in triangle T_j according to Harris-Stephens interest point strength [6]. A triangles hierarchy is then established, by assigning a score S_j to T_j:

$$S_j = \omega_1 A_j + \omega_2(1 - dist(T_j,\mathbf{c})) + \omega_3 Text_j + \omega_4 str_j, \tag{8}$$

where ω_i, $i = 1,\ldots,4$, are positive weights.

QIM solutions can provide a high level of robustness against attacks such as JPEG compression, filtering or noise addition. However, they tend to be fragile against geometric distortions. Adopting the (α,β) domain as the embedding space of a quantization-based watermarking solution can enhance the robustness of scheme. However, in order to compute the normalized embedding regions, interpolation is required, which will lead to an irretrievable loss of information. In this section, we present two versions of a QIM watermarking algorithm: while one applies interpolation to obtain the affine invariant domain, the other one avoids interpolation by embedding the watermark into a pre-selected set of coordinates.

2.1 Watermark encoding

The watermarking encoding comprises the following steps:

1. Establish the triangles hierarchy.
2. Select the p best-ranked non-overlapped triangles $T_i, i = 1, \ldots, p$.
3. For each triangle T_i:
   (a) i. If interpolation is not used, the pixel intensities of a pre-selected set of pixel coordinates (α_j,β_k), $j = 1, \ldots, L_1$ and $k = 1, \ldots, L_2$ are stored into a vector $\mathbf{x_i}$. Pre-selected coordinates that do not have a corresponding intensity are discarded.
   ii. If interpolation is used, the triangle T_i is mapped into a triangle $\tilde{T}_i$ in (α,β) coordinates (computed via interpolation). The pixel intensities of the normalized triangle are stored in the vector $\mathbf{x_i}$.
   (b) Generate pseudo-randomly, based on a secret key, the dither vector $d[.,0]$ with an uniform distribution over $[-\frac{\Delta}{2}, \frac{\Delta}{2}]$, where Δ is the quantization step and $d[\cdot,1]$ is given by

$$d[n,1] = \begin{cases} d[n,0] - \frac{\Delta}{2} & \text{if } d[n,0] > 0 \\ d[n,0] + \frac{\Delta}{2} & \text{if } d[n,0] \le 0 \end{cases} . \quad (9)$$

   (c) Encode each bit m_n into the $n - th$ sample of $\mathbf{x_i}$: $\mathbf{x_{i_n}} = Q(\mathbf{x_{i_n}} + d[n,mn],\Delta) - d[n,m]$, where $Q(\cdot)$ is the quantizer.

2.2 Watermark decoding

Concerning watermark decoding, the following operations have to be performed:

1. Establish the triangles hierarchy.
2. Select the q $(p < q)$ best-ranked non-overlapped triangles Ti, $i = 1, \ldots, q$.
3. For each triangle T_i:
   (a) i. If interpolation is not used, store the pixel intensities of a pre-selected set of pixel coordinates (α_j,β_k), $j = 1, \ldots, L_1$ and k=1,. . . ,L2 into a vector $\mathbf{z}$. If pre-selected coordinates do not have a corresponding intensity in the Cartesian plane, they are discarded.
   ii. If interpolation is used, map T_i into a triangle $\tilde{T}_i$ in (α,β) coordinates (computed via interpolation). The pixel intensities of the normalized triangle are stored in the vector $\mathbf{z}$.
   (b) Generate pseudo-randomly, based on a secret key, the dither vector $d[.,.]$.
   (c) Estimate the message bit $\hat{m}_n$ in a way that the following distance will be minimized:

$$\hat{m}_n = \arg\min \|\mathbf{z_n} - Q(\mathbf{z_n} + d[n,m_n],\Delta)\|^2 ,$$

   where $m_n \in \{0,1\}$.

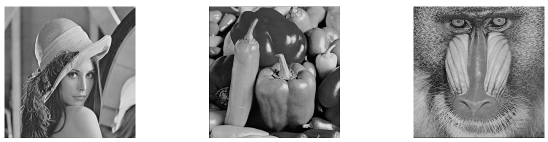
3. Experimental Results and Discussion

In order to assess the relevance of avoiding interpolation operations during the watermark insertion and extraction in terms of effectiveness/robustness of the whole watermarking system, we have chosen three test images: ”Lena”, ”Peppers” and ”Baboon” (512×512 pixels, 256 graylevels), as shown in Figure 4(a), to be marked according to the two versions of the QIM solution described in the previous section. When interpolation was applied, a grid with 80× 80 samples was used to represent the triangles in (α,β) coordinates. The message ”INFO” was embedded into the test images, being selected only one triangle for embedding. Figures 4(b) and (c) show the absolute difference between the original images and their marked versions, using the proposed watermarking strategy, respectively with and without interpolation. Table 1 summarizes the weighted peak signal-to-noise ratios and quantization steps for different test-images. The weighted peak signal-to-noise ratio ($wPSNR$) we used to measure the visual distortion took into account the texture level estimated by the *Noise Visibility Function*. This distortion measure is given by Eq. (10):

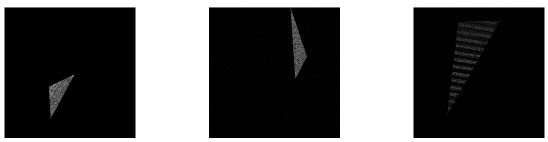
$$wPSNR = 10 \times \log_{10}\left(\frac{L_{max}}{\sqrt{\frac{\sum_{k=1}^{n}\sum_{l=1}^{m}[(I_O(k,l)-I_M(k,l))\times NVF(k,l)]^2}{n\times m}}}\right)^2, \quad (10)$$

where L_{max} represents the maximum luminance value, $I_O(\cdot,\cdot)$ and $I_M(\cdot,\cdot)$ denote the original and marked images, respectively, with $n \times m$ pixels and $NVF(k,l)$ is the *Noise*

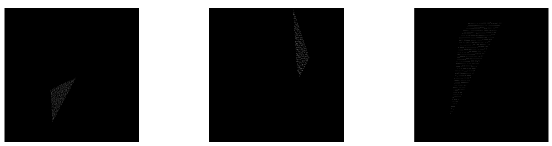
Visibility Function at pixel (k,l). Since interpolation is avoided and contiguous pixels are not selected for modification, higher quantization steps are allowed which enhances the robustness of the scheme. However, if we decide to mark the whole triangle, image fidelity can be severely degraded.



(a)



(b)



(c)

Figure 4. (a) Test images; (b)Difference (20 times the absolute difference), watermarking with interpolation; (c) Difference (20 times the absolute difference), watermarking without interpolation;

(a) (b) (c)

Figure 5. (a) Test image "Peppers"; (b) "Peppers" embedding triangle in Cartesian coordinates; (c) "Peppers" embedding triangle in (α,β) coordinates.

As shown in Table 1, by avoiding interpolation, *i.e.*, using only a set of pre-selected coordinates to be marked, higher *wPSNR* values can be obtained. Regarding image manipulations over the marked content, we applied distortions such as JPEG compression, filtering, noise addition and several geometric transformations including scaling, rotation and cropping. Concerning extraction, the watermark presence was checked in the 6 highest ranked triangles according to the hierarchy given in the previous section, taking into account the 6 possible permutations of vertices for each triangle. Tables 2 and 3 list the extraction results in terms of the minimum bit error rate. The character '-' means that at least one of the vertices from the embedding triangle was not detected during the extraction stage. When interpolation was not applied, the scheme proofed to be more effective. Regarding geometric distortions, by avoiding interpolation, the method exhibited a high level of robustness; the most critical transformation was the scale change by a factor of 0.5, fundamentally due to the loss of information carried out by the resizing. The method showed a lower robustness when applied to the "Baboon" image, since it is a highly textured image, being, therefore, subject to a less accurate interpolation. In conclusion, the (α,β) domain when combined with QIM watermarking solutions can be quite effective if no interpolation is applied during the watermark encoding and decoding stages. Moreover, we are able to achieve a better trade-off between robustness and imperceptibility.

Image	*wPSNR*		Δ
	without interpolation	with interpolation	(quantization step)
"Lena"	59.146 dB	44.218 dB	40
"Peppers"	68.591 dB	45.695 dB	40
"Baboon"	63.797 dB	43.532 dB	60

Table 1. Weighted peak signal-to-noise ratios and quantization steps for the test images.

Attacks	"Lena"		"Peppers"		"Baboon"	
	Interpolation		Interpolation		Interpolation	
	×	√	×	√	×	√
Rotation (5 deg.)	0	0.5	0	0.1786	0	-
Rotation (15 deg.)	0	0.4286	0	0.0357	0.1429	-
Rotation (25 deg.)	0	0.5	0	0.1071	0.1429	0.5357
Cropping (≃ 20%)	0	0.3571	-	-	0	0.4286
Scaling (×1.2)	0	-	0	0.0714	0.0714	0.6429
Scaling (×0.9)	0	0.3929	0	0.1071	0.0714	-
Scaling (×0.8)	0	0.5	0	0.25	0.1429	0.6786
Scaling (×0.5)	-	-	-	-	-	-
Scaling (×0.8) + Rotation (20 deg.)	0	-	0	0.0357	-	-
Scaling (490 × 410 *pixels*)	0	0.4643	0	0.1786	-	0.5714

Table 2. Extraction results, in terms of bit error rate, after geometric attacks.

Attacks	"Lena"		"Peppers"		"Baboon"	
	Interpolation		Interpolation		Interpolation	
	×	√	×	√	×	√
JPEG (Q=75%)	0	0.3571	0	0.1071	0	0.4286
JPEG (Q=50%)	0	0.3571	0	0.1071	0	0.5
JPEG (Q=25%)	-	-	-	-	0.2857	0.537
Median filter (3×3)	0	0.1429	0	0.1429	-	-
Gaussian noise (3%)	0	0.25	0	0.1071	0.1429	0.4286
Edge enhancement	0	0.2143	0	0.0357	0	0.25

Table 3. Extraction results, in terms of bit error rate, after JPEG compression, noise addition or filtering.

4. Conclusions and Future Work

In this paper, we have analyzed two versions of a QIM watermarking scheme providing robustness with respect to a wide range of geometrical distortions by locally embedding the watermark into an affine invariant domain. The effects of the presence of an interpolation stage in the whole watermarking process were studied. The invariant space, the (α,β) domain, is obtained, firstly, by detecting affine invariant interest points and defining triangle-shaped image regions identified by the points. The remainder of the process is a triangle normalization, carried out by mapping into a coordinate system, based on barycentric coordinates, which is invariant to affine transformations.
Regarding the possibility of designing a robust watermarking scheme without performing any interpolation operations during the watermarking process, we have combined the proposed space with a QIM watermarking strategy, yielding on a robust watermarking system if interpolation is avoided. Furthermore, robustness and imperceptibility were both increased since not all pixels in the selected embedding area are modified, allowing higher quantization steps for watermark coding. A second watermarking scheme comprising interpolation stages was analyzed. In this case, despite the complete pixel modification in the embedding area, distortions induced by interpolation led to an exceptionally inaccurate watermark decoding.

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